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13. ABSTRACT We have spent a great deal of effort in GaN as well as in ZnSe due to the rapid and more promising development of GaN recently. We have performed intensive material study on GaN, such as DLTS, TSC, photocurrent spectroscopy, and x-ray, to understand its defect nature. The major achievements of last year's work in our laboratory can be summarized as follows. (1) We are the first group to observe the transferred-electron effect in GaN. We observed a negative differential resistivity (NDR) in GaN under high electric field. The threshold electrical field was found to be around 1.91×10^5 V/cm. The NDR of GaN can be used in the application of high-temperature Gunn diodes. (2) We have performed a systematic studies on GaN M-S-M ultraviolet detectors made from GaN grown by MOCVD under different NH_3 flow rates. We have found that a 0.62 eV deep trap which was attributed to gallium antisites or nitrogen vacancy-related defects was responsible for the low responsivity and the slow response time in GaN UV detectors. In addition, this 0.62 eV level can be effectively reduced by increasing the NH_3 flow rate during the MOCVD growth. As a result, a high-performance UV detector was fabricated on GaN of the lowest 0.62 eV trap. This detector has a responsivity as high as 3200 A/W under 5 V at a wavelength of 365 nm and improved response times in the sub-milliseconds range.				
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Annual Report to ARO by Dr. J. C. Chen, Dept.of EE, UMBC

Both GaN and ZnSe based materials are wide-band-gap compound semiconductors ideally suited for devices in the visible-to-ultraviolet region of the spectrum. Laser diodes and LEDs have been successfully demonstrated using both materials. Due to the rapid and more promising development of GaN recently [1], we also spent a great deal of effort in GaN besides in ZnSe.

In order to grow GaN, we have to modify our MOCVD system. Since the growth temperature of GaN is much higher than that of ZnSe, we have to use a RF heater instead of an IR heater to reach more than 1000° C. A 7.5 KW RF heater has been installed and tested up to 1200C. In addition, we also obtained the "highest purity" ammonia from Solktronic Chemicals, Inc., (SCI, a major supplier of high-purity semiconductor industry gas). In the last few years, SCI has spent tremendous efforts in improving the purity of ammonia. Recently, the so-called "blue-ammonia" was purified by a special process and tested with all impurities less than 50 ppb. It has been shown that the impurities (especially oxygen and moisture) in ammonia is one of the major obstacles in the growth of high-purity GaN [2]. Through the long term cooperation between SCI and UMBC, SCI agreed to provide the first blue-ammonia to us free of charge. The study using blue-ammonia is now underway. We believe that some breakthrough can be achieved soon by using high growth temperatures and high-purity ammonia.

Moreover, we have performed several characterization techniques, such as DLTS, TSC, photocurrent spectroscopy, and x-ray, on our previous GaN samples to understand its defect nature. Some important results are listed below and some of them have been published or submitted to Applied Physics Letters or other journals. We have received a lot of requests of our reprints from companies and research institutes worldwide.

Key discovery:

The major results of last year's work in our laboratory can be summarized as follows.

- (1) We are the first group to observe the transferred-electron effect in GaN [3]. Figure 1 shows a current-electric field (I-E) curve of GaN using a metal-semiconductor-metal (MSM) structure. It clearly shows a negative differential resistivity (NDR) in GaN under high electric field. The threshold electrical field was found to be around 1.91×10^5 V/cm. The NDR of GaN can be used in the application of high-temperature Gunn diodes.
- (2) In collaboration with NASA and the Applied Physics Lab. of JHU, we have performed a systematic studies on GaN M-S-M ultraviolet detectors made from GaN grown by MOCVD under

Annual Report of Scientific Accomplishments

by Dr. J. C. Chen, Dept. of EE, Univ. of Maryland Baltimore Campus (UMBC)

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(3) The defects in GaN characterized by thermally stimulated current (TSC) spectroscopy and photocurrent spectroscopy also show interesting behavior [5].

(4) Besides the study of GaN, several studies related to other wide-gap materials were also performed [6-7].

Summary and future plan:

We have achieved some in-depth understanding of the defect formation on GaN using various characterization techniques. We also upgraded our MOCVD system and source materials during the period of this project. Based on these achievements, we will continue to optimize our GaN growth and doping study in the next step.

References:

- [1] S. Nakamura, M. Senoh, and T. Mukai, "High-power InGaN/GaN double-heterostructure violet light emitting diodes," Appl. Phys. Lett., 62, pp. 2390, 1993
- [2]. B. C. Chung and M. Gershenson, The influence of oxygen on the electrical and optical properties of GaN crystals grown by MOVPE," J. Appl. Phys. 72, pp. 651, 1992.
- [3]. Z. C. Huang, J. C. Chen, Y. Zheng, B. Mott, and P. Shu "Direct observation of transferred-electron effect in GaN", Applied Physics Letter, 67, 2825, 1995.
- [4]. Z. C. Huang, J.C.Chen, Dennis Wickenden, Brent D. Mott, and P Shu, "Effects of ammonia on the performance of GaN ultraviolet detectors", Submitted to Applied Physics Letter.
- [5]. Z. C. Huang, J. C. Chen, B. Mott and P. Shu "Study of deep levels in insulating GaN using thermally stimulated current and photocurrent spectroscopies" Submitted to Applied Physics Letter.
- [6]. J.C. Chen, Bing Yang, L. H. Kuo, L. Salamanca-Riba, F. Semendy and N. Bambha "Very low defect density ZnSe grown on GaAs by MOCVD" Materials Chemistry and Physics (Elsevier) (in press).
- [7]. J. C. Chen, Z. C. Huang, K.J. Lee and R. Kanjolia "Effects of TMIn on the purity of InAlP and InAlAs grown by MOCVD", Submitted to J. of Electronic Material.

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J. C. Chen, Z. C. Huang, Bing Yang, TaoYu, H. K. Chen and K. J. Lee, "Effects of Se-doping on the deep impurities of AlGaAs" J. of Electronic Materials, 24, pp.1677-1682, 1995.

L. H. Qin, Y. D. Zheng, D. Feng, Z. C. Huang, and **J. C. Chen**, "Optical characterization of GaN films by photoreflectance and photoreflectance and photocurrent measurement" J. of Applied Physics, 78, 7424, 1995.

R. Zhang, K. Yang, L. H. Qin, B. Shen, H. T. Shi, Y. Shi, S. L. Gu, Y. D. Zheng, Z. C. Huang, and **J. C. Chen**, "Optical properties of Gallium Nitride films grown by MOCVD" J. of Vacuum Science and Technology A, (accepted).

J. C. Chen, Z. C. Huang, K.J. Lee and R. Kanjolia "Effects of TMIn on the purity of InAlP and InAlAs grown by MOCVD", Submitted to J. of Electronic Material.

Z. C. Huang, **J. C. Chen**, Y. D. Zheng, and D. B. Mott "Negative resistivity in GaN MSM photoconductors" Material Research Society Fall Symp. Proceeding, 1995 (in press).

Z. C. Huang, **J. C. Chen**, and D. B. Mott "Metastable states in GaN studied by thermally stimulated current spectroscopy" Material Research Society Fall Symp. Proceeding, 1995 (in press).

Z.C. Huang, **J.C.Chen**, Dennis Wickenden, Brent D. Mott, and P Shu, "Effects of ammonia on the performance of GaN ultraviolet detectors", Submitted to Applied Physics Letter.

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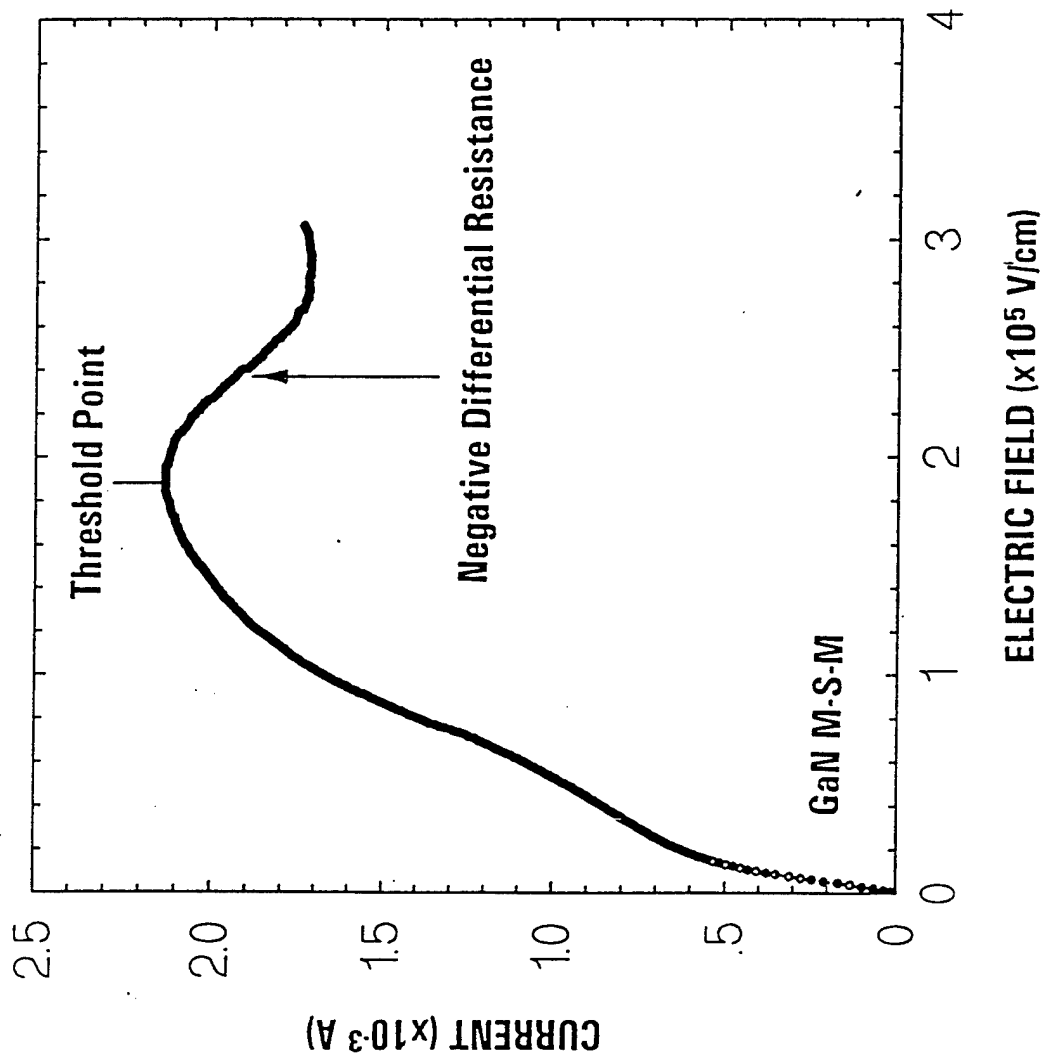


Figure 1. I-E curve at room temperature for GaN M-S-M system

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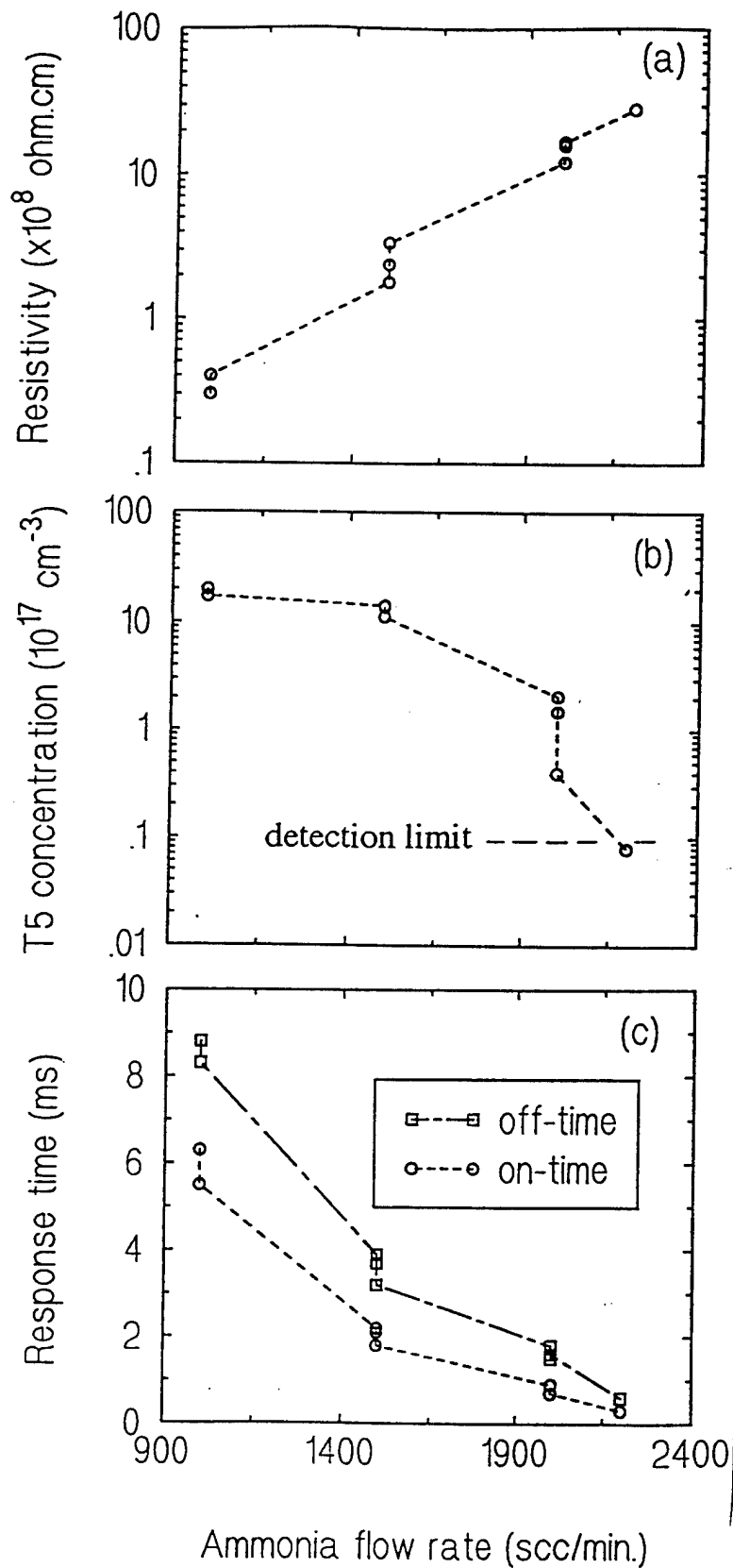


Figure 2. The measured resistivity, concentration of trap T5 and the response time as a function of NH_3 flow rate in GaN.

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